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Raising Practices of Neolithic Livestock Evidenced by Stable Isotope Analysis in the Wei River Valley, North China

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ABSTRACT Although a patchwork of projects shows a process of agriculture intensification in North China during the Neolithic, the impact of cereal farming on animal husbandry and their mutual interaction remain cloudy. This study reports bone collagen $\delta^{13}C$ and $\delta^{15}N$ of humans and animals from Wayaogou (ca 6.5–6.0 kyrs BP) and Dongying (ca 5.9–5.6 kyrs BP, 4.6–4.0 kyrs BP) to explore temporal trend of livestock raising and particularly the importance of millet fodder to stock raising practices in the Wei River valley, North China. The isotopic evidence overall shows that millet products increased in human and domestic animal diets during the mentioned chronological span. $\delta^{13}C$ values of pigs and dogs at Dongying are higher than those at Wayaogou, implying that the importance of millet nutrients increased to animal husbandry diachronically. Interestingly, $\delta^{13}C$ results of domestic cattle of Dongying late phase (−14.1 ± 1.1‰, N = 5) are more enriched than Wayaogou wild *Bos* (−17.8 ± 0.3‰, N = 3), indicating that millet fodder had taken a significant place in early cattle husbandry. Besides, differences between *Bos* species of the two periods also imply that $\delta^{13}C$ values of bone collagen constitute a potential indicator for tracing the origin of cattle husbandry in North China. In addition, domestic sheep at Dongying produced similar isotope data to wild ovicaprid at Wayaogou, suggesting that they possibly had grazed for the most in grassland and therefore experienced a different lifestyle from cattle. Copyright © 2014 John Wiley & Sons, Ltd.

Key words: carbon; isotopes; livestock raising; nitrogen; the Neolithic; the Wei River valley

Introduction

Understanding how animal husbandry evolves over time is key to reveal the shift of human subsistence and adaption in the course of the Neolithic. In particular, it is important to trace mutual interaction between livestock and crop production systems during the early stage of human society. It is generally accepted that North China is one of the important centres of plant (millets) and animal (dog and pig) origins in the world (Yuan *et al.*, 2008; Zhao, 2011). However, the impact of cereal farming on animal raising practices and their mutual interaction are still poorly understood. The Wei River valley (Figure 1), one of the critical regions in North China yielding substantial amount of animal remains, including the local domesticates (dogs and pigs) and possibly exotic domesticates (sheep and cattle) imported from the West (Flad *et al.*, 2007; Lü, 2010), allows us to explore how animal husbandry developed along with the prosperity of farming during the Neolithic.

Laoguantai culture (ca 8.5–6.9 kyrs BP) represents the earliest period of man-manipulated food production in the Wei River valley, namely millet cultivation and pig and dog husbandry, although hunting and gathering were still the principal practices in human lifeways (Lang, 2003; Liu, 2006; Barton *et al.*, 2009; Atahan *et al.*, 2011). By contrast, during Yangshao period (ca 6.9–5.0 kyrs BP), great intensity of crop production is revealed by high frequency of millet remains, which were staple to farmers as well as pigs and dogs (Pechenkina *et al.*, 2005; Barton *et al.*, 2009; Zhao, 2011; Shang *et al.*, 2012). When it came to

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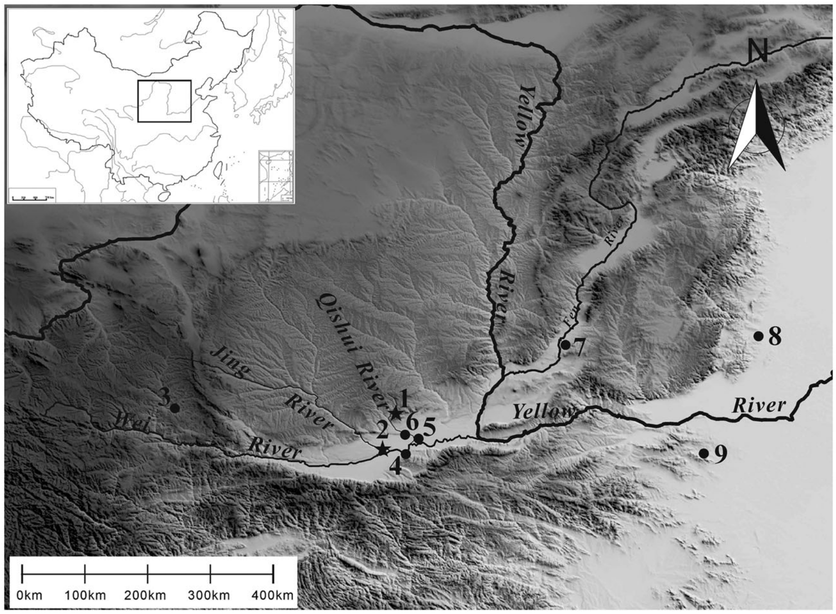

Figure 1. Location of archaeological sites mentioned in and around the Wei River valley: (1) Wayaogou, (2) Dongying, (3) Dadiwan, (4) Jiangzhai, (5) Kangjia, (6) Baijia, (7) Taosi, (8) Zhangdeng and (9) Xinzhai.

Longshan period (ca 5.0–4.0 kyrs BP), the production of cereals and livestock were intensified and diversified. Besides millets, rice, another cultivar originated in Yangtze River Valley, spread to North China and became one of the important crops (Zhao & Xu, 2004; Zhang *et al.*, 2010a). Meanwhile, large numbers of sheep and cattle remains were found except for the pigs and dogs (Li *et al.*, 2007; Luo, 2009; Lü, 2010).

In this study, Wayaogou (瓦窯溝) and Dongying (東營) at the Wei River valley in Shaanxi Province, China, dated to Yangshao Culture period and Longshan Culture period respectively, were chosen. The stable isotope compositions of animal and human bones from the two sites were measured and analysed here in order to explore the relationship between animal husbandry and cereal production and its diachronic shift.

Stable carbon and nitrogen isotopes and palaeodiet study

In the past decades, stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis has become a routine procedure in archaeological research to reconstruct human or animal diets and subsistent strategies (i.e. Richards *et al.*, 2003; Noe-Nygaard *et al.*, 2005). Stable carbon isotopes often provide an estimate on the consumption of C_3 versus C_4 plants in terrestrial foodwebs. C_3 and C_4 plants are distinguishable in the photosynthetic pathways (Smith & Epstein, 1971; O'Leary, 1981). C_3 plants discriminate more against ^{13}C during CO_2 fixation and consequently produce lower $\delta^{13}C$ values than C_4 plants. $\delta^{13}C$ in modern C_3 and C_4 plants in the Wei River valley and surrounding region are −27.5‰ (from −28.5‰ to −24.4‰) and −12.6‰ (from −14.6‰ to −10.5‰), respectively (Wang *et al.*, 2003; Wang *et al.*, 2005). Foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) are typical C_4 cereals with $\delta^{13}C$ values close to −13.0‰ (Yang *et al.*, 2011). Given the fossil fuel effect (Marino & Mcelroy, 1991), the $\delta^{13}C$ values of prehistoric millets may be around −11.5‰. The isotopic difference between the two categories of plants would be transferred in the foodwebs with substantial isotopic fractionation. For mammals, the isotopic enrichment from diet to bone collagen is about 5‰ although this value can vary to some extent due to the different composition of macro-biomolecules in foods (DeNiro & Epstein, 1978; van der Merwe & Vogel, 1978; Lee-Thorp *et al.*, 1989; Ambrose & Norr, 1993; Jim *et al.*, 2006; Fernandes *et al.*, 2012). Thus, bone collagen $\delta^{13}C$ values can tell the consumption of specific plant-based foods, either from the plant itself or the animals preying on the plants.

Different from carbon isotopes, nitrogen isotopes are typically used to estimate trophic levels for the organism. It is based on the assumption that body tissue $\delta^{15}N$ values of consumers are generally elevated over those of their diet by 3–5‰ (DeNiro & Epstein, 1981; Bocherens & Drucker, 2003; Hedges & Reynard, 2007), although the enrichment value fluctuates because of the influential factors such as food quality (Sponheimer *et al.*, 2003; Robbins *et al.*, 2005), physiological press (Fuller *et al.*, 2005; Haubert *et al.*, 2005) and environment (Hartman, 2011). In addition, some other factors affecting plant $\delta^{15}N$ values, such as soil condition (i.e. aridity and salinity) and manuring effects, may have some substantial influences on the $\delta^{15}N$ values of animal or human bone collagen as well (Ambrose, 1991; Choi *et al.*, 2003; Bogaard *et al.*, 2007).

Archaeological background

The Wei River valley forms part of the Yellow River basin in North China and was typically occupied by millet farmers during the Neolithic. The paleoenvironmental studies in the region suggest that the climate was temperately warm and semi-humid and that the sparse-wood grasslands were the dominant vegetation during the Holocene (An *et al.*, 2000; Porter & Zhou, 2006; Shang & Li, 2010). $\delta^{13}C$ values of the total organic matter of palaeosol (approximately −24‰ to −18‰) indicate that the vegetation of North China Loess Plateau during the Holocene was dominated by C_3 plants (Liu *et al.*, 2005; Ning, 2010).

The Wayaogou site (34°59′58″N; 109°1′34″E, 734 m a.s.l.) is situated on the left terrace of Qishui river, a tributary of the Wei River in the northern margin of the Wei River valley. Radiocarbon dates (Lab of Institute of Archaeology, 1994) on charcoal among Neolithic deposits show an occupation during 6268–5320 cal BP, whereas the excavators (Wang, 1998; Wang, 2011) suggested that the site can be dated to ca 6.5–6.0 kyrs BP according to the analysis of pottery typology (Table 1). Fauna assemblages at the site include a wide range of animal species, including deer, pig, ovicaprid and bovid, among which the deer (56.4%) and pigs (38.4%) were predominated (Wang, 2011).

The Dongying site (34°26′36″N; 109°0′55″E, 372 m a.s.l.) is 60 km away from Wayaogou in the southeast and overlooks the confluence of the Jing and Wei Rivers. On the basis of typological analysis of artefacts, primarily on pottery, the duration are divided into two phases, namely DY-1 and DY-2, attributed to the Miaodigou culture (ca 5.9–5.6 kyrs BP) and Kexingzhuang II culture (ca 4.6–4.0 kyrs BP), respectively (Shaanxi Provincial Academy of Archaeology, 2010). The presence of animal species is diverse, including dogs, pigs, deer, sheep and cattle. Pig (20.0%, 30.9%) and deer (70%, 34.7%) were still dominant in the fauna assemblages during both phases (Hu, 2010).

Materials and methods

Fifty-seven animal samples were chosen, including pig, dog, bovid, ovicaprid, water buffalo, cervid, equid, rabbit and pheasant, among which 29 came from Wayaogou, four from DY-1 and 24 from DY-2 (Table 2). In addition, five human samples from DY-2 were also included.

All samples were prepared following the protocol described by Jay & Richards (2006) with some modifications. The bones were mechanically cleaned and demineralised in 0.5 M HCl at 4°C. Afterwards, the remains were washed into neutrality with deionised H_2O and immersed in 0.0125 M NaOH at room temperature for 24 h. The remains were washed again into neutrality and plunged into HCl solution (pH = 3) at 75°C for 48 h to make the bone gelatinised. After the filtration, the solution was frozen and freeze-dried to get the collagen. The collagen yield (%) was calculated as the collagen weight divided by the bone weight.

Table 1. Chronology of study sites

Site	Phase	^{14}C dating (cal BP)	Archaeological Age (BP)	Reference
Wayaogou	Banpo	5909–5663, 6268–5911, 5647–5386, 5599–5338, 5584–5320	ca 6500–6000	(Lab of Institute of Archaeology, 1994; Wang, 1995; Wang, 1998)
Dongying	DY-1		ca 5900–5500	(Baoji Archaeological Team & Shaanxi Provincial Institute of Archaeology, 1993; Shaanxi Provincial Institute of Archaeology, 2010)
	DY-2		ca 4600–4000	(Baoji Archaeological Team & Shaanxi Institute of Archaeology, 1993; Shaanxi Provincial Institute of Archaeology, 2010)

Table 2. Archaeological background, extraction results and isotope values for samples of Wayaogou and Dongying

Lab ID	Site	Context	Phase	Taxon	Collagen%	C%	N%	C/N	δ^{13}C‰	δ^{15}N‰
WYG1	Wayaogou	H17:39	Wayaogou	Pig (*Sus domestica*)	1.7	42.2	15.7	3.1	−16.6	7.2
WYG2	Wayaogou	H124:21	Wayaogou	Pig (*S. domestica*)	0.1	39.1	14.2	3.2	−10.7	5.9
WYG3	Wayaogou	H139:35	Wayaogou	Pig (*S. domestica*)	0.7	41.7	15.4	3.2	−17.6	4.7
WYG4	Wayaogou	***H150*:*144***	Wayaogou	**Pig (*S. domestica*)**	—	—	—	—	—	—
WYG5	Wayaogou	H156:84	Wayaogou	Pig (*S. domestica*)	1.8	42.7	15.8	3.2	−17.0	5.4
WYG6	Wayaogou	H167:25	Wayaogou	Pig (*S. domestica*)	0.8	43.3	15.9	3.2	−9.0	6.3
WYG7	Wayaogou	H199:533	Wayaogou	Pig (*S. domestica*)	0.7	41.6	15.2	3.2	−10.9	6.4
WYG8	Wayaogou	H156:104	Wayaogou	Pig (*S. domestica*)	1.1	42.5	15.6	3.2	−10.1	6.2
WYG9	Wayaogou	H227:21	Wayaogou	Pig (*S. domestica*)	0.7	40.3	14.8	3.2	−12.4	5.0
WYG10	Wayaogou	H70:16	Wayaogou	Dog (*Canis familiaris*)	7.3	43.8	16.1	3.2	−11.0	9.7
WYG11	Wayaogou	H197:55	Wayaogou	Dog (*C. familiaris*)	4.7	44.8	16.5	3.2	−10.9	7.1
WYG12	Wayaogou	H156:22	Wayaogou	Dog (*C. familiaris*)	4.9	39.3	14.5	3.2	−11.3	9.7
WYG13	Wayaogou	H72:B46?	Wayaogou	Bovid (*Bos* sp.)	0.6	43.9	16.2	3.2	−17.5	6.0
WYG14	Wayaogou	H79:B43	Wayaogou	Bovid (*Bos* sp.)	4.1	41.6	15.4	3.2	−18.0	6.3
WYG15	Wayaogou	***H170*:*14***	Wayaogou	**Bovid (*Bos* sp.)**	—	—	—	—	—	—
WYG16	Wayaogou	T26H70:B22	Wayaogou	Bovid (*Bos* sp.)	2.6	42.7	15.7	3.2	−17.8	4.5
WYG17	Wayaogou	T26H70:B10	Wayaogou	Ovicaprid (*Ovis* sp.)	8.3	44.4	16.3	3.2	−17.6	6.7
WYG18	Wayaogou	T26H72:B40	Wayaogou	Ovicaprid (*Ovis* sp.)	3.9	46.9	17.3	3.2	−17.3	8.4
WYG19	Wayaogou	H13:235	Wayaogou	Pheasant (*Gallus* sp.)	0.1	38.5	14.3	3.1	−16.9	5.2
WYG20	Wayaogou	H149:43	Wayaogou	Pheasant (*Gallus* sp.)	1.3	43.3	16.0	3.2	−16.8	5.4
WYG21	Wayaogou	H96:379	Wayaogou	Pheasant (*Gallus* sp.)	6.8	42.6	15.5	3.2	−15.7	5.2
WYG22	Wayaogou	H180:123	Wayaogou	Cervid (*Cervus nippon*)	1.7	43.3	15.9	3.2	−20.1	4.1
WYG23	Wayaogou	H180:124	Wayaogou	Cervid (*C. nippon*)	5.0	45.6	16.8	3.2	−20.1	3.5
WYG24	Wayaogou	H180:125	Wayaogou	Cervid (*C. nippon*)	3.0	42.6	15.7	3.2	−20.3	3.9
WYG25	Wayaogou	H180:126	Wayaogou	Cervid (*C. nippon*)	0.9	43.5	16.0	3.2	−19.9	4.3
WYG26	Wayaogou	H180:130	Wayaogou	Cervid (*C. nippon*)	0.5	44.8	16.4	3.2	−19.3	7.6
WYG27	Wayaogou	H180:131	Wayaogou	Cervid (*C. nippon*)	2.9	42.5	15.7	3.2	−19.8	4.3
WGY28	Wayaogou	H199:513	Wayaogou	Cervid (*Moschus moschiferus*)	1.7	41.9	15.4	3.2	−20.6	4.6
WYG29	Wayaogou	H216:44	Wayaogou	Cervid (*M. moschiferus*)	1.8	40.7	15	3.2	−21.6	5.8
DY1	Dongying	T2710②H41:11	DY-1	Pig (*S. domestica*)	1.6	42.4	15.6	3.2	−9.8	6.1
DY2	Dongying	T2710②H41:59	DY-1	Pig (*S. domestica*)	6.5	44.4	16.3	3.2	−9.2	7.7
DY3	Dongying	T1408③h5:15	DY-2	Pig (*S. domestica*)	6.8	45.5	16.8	3.2	−14.6	6.3
DY4	Dongying	T1408③h5:16	DY-2	Pig (*S. domestica*)	6.0	43.9	16.3	3.1	−15.4	5.9
DY5	Dongying	T1②H66:2	DY-2	Pig (*S. domestica*)	3.5	43.3	16.1	3.1	−8.0	7.5
DY6	Dongying	T1②H66:3	DY-2	Pig (*S. domestica*)	1.6	42.5	15.6	3.2	−7.8	9.1
DY7	Dongying	2#④H4:1	DY-2	Pig (*S. domestica*)	2.5	41.2	15.3	3.1	−8.2	7.6
DY8	Dongying	T2810②:2	DY-2	Pig (*S. domestica*)	1.3	40.1	15.0	3.1	−9.5	7.1
DY9	Dongying	T2709③H6:1	DY-2	Pig (*S. domestica*)	1.5	39.8	14.9	3.1	−9.7	7.4
DY10	Dongying	T1408③h5:7	DY-2	Dog (*C. familiaris*)	5.7	41.9	15.5	3.1	−14.6	6.9
DY11	Dongying	T2810②:29	DY-2	Dog (*C. familiaris*)	0.5	40.8	15.1	3.2	−9.1	5.9
DY12	Dongying	T1②H66:33	DY-2	Cattle (*Bos* sp.)	3.1	44.6	16.5	3.2	−13.8	7.5
DY13	Dongying	T1②H66:35	DY-2	Cattle (*Bos* sp.)	0.9	37.4	13.8	3.2	−15.5	7.0
DY14	Dongying	T2810②H55:1	DY-2	Cattle (*Bos* sp.)	3.0	44.1	16.2	3.2	−13.3	7.6
DY15	Dongying	2#④H72:10	DY-2	Cattle (*Bos* sp.)	6.1	44.9	16.4	3.2	−13.1	5.6
DY16	Dongying	T1810H62④:6	DY-2	Cattle (*Bos* sp.)	1.4	39.5	14.6	3.1	−15.0	8.5
DY17	Dongying	T0809④:32	DY-2	Sheep (*Ovis* sp.)	6.8	45.1	16.6	3.2	−18.9	8.3
DY18	Dongying	T2810②:17	DY-2	Sheep (*Ovis* sp.)	4.6	44.6	16.3	3.2	−16.6	5.9
DY19	Dongying	T2810②:36	DY-2	Pheasant (*Gallus* sp.)	4.4	42.6	15.5	3.2	−12.0	5.5
DY20	Dongying	T1508③h8:5	DY-2	Horse (*Equus* sp.)	4.9	42.8	16	3.1	−16.5	3.8

DY21	Dongying	T1710②H1:1	DY-2	Hare (*Lepus capensis*)	5.7	44.2	16.2	3.2	−16.5	5.3
DY22	Dongying	T2309②H50:2	DY-2	Cat (*Felis* sp.)	4.0	44.4	16.4	3.2	−17.0	7.0
DY23	Dongying	T2409②:3	DY-1	Cervid (*C. nippon*)	1.6	39.1	14.5	3.2	−19.8	3.8
DY24	Dongying	T2710②H41:42	DY-1	Cervid (*C. nippon*)	0.5	41.7	15.3	3.2	−20.5	3.6
DY25	Dongying	T2810②:9	DY-2	Cervid (*C. nippon*)	0.6	39.6	15.1	3.1	−18.9	4.1
DY26	Dongying	T2709③H6:28	DY-2	Cervid (*C. nippon*)	6.4	43.1	15.8	3.2	−21.1	6.3
DY27	Dongying	H72:11	DY-2	Buffalo (*Bubalus* sp.)	2.1	43.2	15.8	3.2	−15.7	7.0
DY28	Dongying	T1②H66:32	DY-2	Buffalo (*Bubalus* sp.)	3.2	43.6	16.1	3.2	−12.6	6.0
DY29	Dongying	2#④H71:1	DY-2	Human (*Homo sapiens*)	7.8	44.5	16.5	3.1	−6.8	9.0
DY30	Dongying	2#④H71:2	DY-2	Human (*H. sapiens*)	5.2	44.4	16.5	3.1	−6.7	9.1
DY31	Dongying	T2309②H50:15	DY-2	Human (*H. sapiens*)	4.6	42.1	15.7	3.1	−8.3	9.6
DY32	Dongying	T1408③h5	DY-2	Human (*H. sapiens*)	3.1	39.8	14.7	3.2	−9.9	9.8
DY33	Dongying	T2309②H50:16	DY-2	Human (*H. sapiens*)	1.0	42.3	15.7	3.1	−8.4	9.4

The stable isotope ratios of bone collagen were analysed by isotope ratio mass spectrometers (IsoPrime 100. Elementar, UK) coupled with EA (Elementar) at the Environmental Stable Isotope Lab, Institute of Environment and Sustainable Development, Chinese Academy of Agricultural Science. The standard for measuring the content of C, N is sulfanilamide. IEAE-N-1 (Ammonium Sulfate) and USGS 24 (Graphite) were used to normalise N_2 (AIR) and CO_2 (Pee Dee Belemnite) in steel bottles, respectively. After 10 samples, an internal standard collagen sample with the average δ^{13}C value of −14.7‰ and average δ^{15}N value of 6.88‰ was inserted into the sample list for calibration and monitoring the stability. The analytical precision for C and N were ±0.2‰. Stable isotopic data are shown in Table 2.

Results

Bone preservation

The preservation of bone collagen is assessed by indexes of collagen yield, carbon and nitrogen percentage yield (%C and %N), and atomic C/N ratios (DeNiro, 1985; Ambrose, 1990; Price *et al*., 1992; van Klinken, 1999). Of the 62 bone samples, two failed to meet the standard of quality required, whereas the others produced relatively well-preserved collagen. Among the collagen of acceptable quality, the collagen yields range from 0.1% to 8.3% by weight, which is much lower than modern bones (~20%), indicating that large part of bone collagen had been decomposed to some degree during long-term burial (Ambrose, 1990). However, %C values range from 37.4% to 46.9%, and %N values range from 13.8% to 17.3%, and all C : N ratios are between 3.1 and 3.2 in collagen, reflecting that those collagen are still well-preserved for stable isotopic analysis.

Wayaogou animal diets

The wide distribution of the data indicates that the diets of the animals were quite variable (Figure 2). Cervids have the most negative δ^{13}C values (−20.2 ± 0.7‰, N = 8) and the lowest δ^{15}N values (4.7 ± 1.3‰, N = 8), which is indicative of a C_3 plant-based diet. In contrast, bovids and ovicaprids have higher δ^{13}C values (−17.8 ± 0.3‰, N = 3 and −17.5 ± 0.2‰, N = 2, respectively), showing a mixed C_3/C_4 diet, which contained a relatively smaller amount of C_4 grasses than C_3 plants. δ^{13}C and δ^{15}N values of pheasants (−16.5 ± 0.7‰, 5.3 ± 0.1‰, N = 3) indicate that they had probably subsisted on a mainly plant-based diet

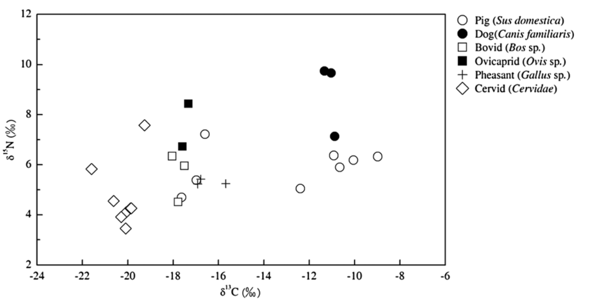

Figure 2. Stable carbon and nitrogen isotope compositions of animal bones at Wayaogou in Wei River valley.

containing substantial amount of C_4 foodstuff, which could be resulted from millet consumption. Pig collagen $\delta^{13}C$ values range from −17.6‰ to −9.0‰ and can be seen in two groups: WYG1, WYG3 and WYG5 with relatively low $\delta^{13}C$ values, and WYG2, WYG6, WYG7 and WYG8 with higher $\delta^{13}C$ values. The latter probably represented those that had consumed more C_4-based nutrients, whereas the former group probably had a diet that was at least isotopically similar to ovicaprids and bovids. Dogs have the highest mean $\delta^{13}C$ and $\delta^{15}N$ values (−11.1 ± 0.2‰, 8.9 ± 1.4‰, respectively, N = 3), which is indicative of large quality of C_4-based protein in their foods.

Dongying human and animal diets

All 28 human and animal samples exhibit $\delta^{13}C$ values ranging from −21.1‰ to −7.8‰ and $\delta^{15}N$ values ranging from 3.6‰ to 9.1‰, respectively, because of large dietary variation among species (Figure 3). It is evident that cervids relied exclusively on C_3 plants, as their bone $\delta^{13}C$ values are fairly negative (−20.1 ± 1.0‰, N = 4). As wild animals, horse and hare display $\delta^{13}C$ values relatively elevated compared with cervids. This suggested that these animals lived in a different habitat, probably with less C_4 plant growth. Sheep $\delta^{13}C$ values are slightly more enriched,

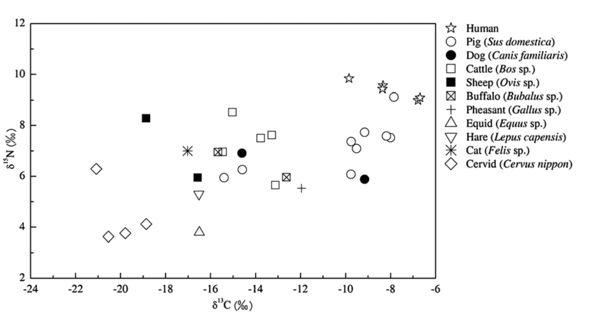

Figure 3. Stable carbon and nitrogen isotope compositions of human and animal bones at Dongying in Wei River valley.

ranging from −18.9‰ to −16.6‰. This is consistent with the isotopic signals of mixed foragers with an emphasis on C_3 plants (i.e. Yacobaccio *et al.*, 2009). With a higher mean $\delta^{13}C$ (−14.3 ± 1.1‰, N = 5), it appeared that cattle might have consumed more C_4 plants than deer and sheep, whereas the relatively elevated $\delta^{15}N$ (7.3 ± 1.1‰) values of the cattle was possibly resulted from different habitats or foraging experience. The two water buffaloes, most likely feral considering no domestic water buffalo in China before the first millennium BC (Liu *et al.*, 2006; Yang *et al.*, 2008), had relatively positive $\delta^{13}C$ values, suggesting that they had incorporated a substantial amount of C_4 plants (−15.7‰ and −12.6‰). These buffaloes were likely supplementing their diet with millets and other C_4 weeds (e.g. *Setaria viridis*) (Pechenkina *et al.*, 2005; Atahan *et al.*, 2011). Alternatively, as buffaloes prefer specific habitats such as wetlands and swamps, grazing hygrophilous plants, for example, sedges (*Cyperus*, C_4 plant), could also cause an enrichment in their $\delta^{13}C$ values (Daniel & Grubh, 1966). The $\delta^{13}C$ value of pheasant is −12.0‰ and markedly higher than those of the herbivores, which suggested the consumption of C_4 plants such as millet.

The $\delta^{13}C$ values of pigs range from −9.9‰ to −7.8‰ with three exceptions that displayed unusually elevated $\delta^{13}C$ values around −15‰. Dogs display relatively similar collagen $\delta^{13}C$ values (−11.9 ± 3.9‰, N = 2), suggesting that their diet was dominated by millet-related resources. Dogs (6.4 ± 0.7‰, N = 3) display lower mean $\delta^{15}N$ value than pigs (7.2 ± 2.4‰, N = 3), which was probably a result from having less animal protein in their diet. The felid, which is a carnivore, yielded $\delta^{13}C$ and $\delta^{15}N$ values of −17.2‰ and 7.0‰ respectively, suggesting that it probably mostly preyed on C_3 food consumers of a low trophic level. The $\delta^{13}C$ values of the five humans group tightly around −8.0‰, reinforcing their emphasis on C_4 foods, most significantly millets and millet-fed animals. They displayed relatively higher $\delta^{15}N$ values (9.0–9.8‰) compared with those of the herbivores (including all ruminants and equid and hare, 6.3 ± 1.4‰, N = 13) and omnivores (pigs, 7.3 ± 1.0‰, N = 7).

Discussions

Subsistence at Dongying

Pilot stable isotope studies suggest that millets were staple in human diet during Yangshao period in the Wei River valley (Pechenkina *et al.*, 2005; Zhang *et al.*, 2010b; Guo *et al.*, 2011). It appeared that

Dongying residents also concentrated significantly on millet-related nutrients and that rice consumption was fairly rare if any according to their high $\delta^{13}C$ values, although charred rice and rice phytolith were occasionally detected in Longshan archaeobotanical remains of the region (Zhao & Xu, 2004; Zhang *et al.*, 2010a). Obviously, ingestion of millet-related animal products was a big factor that increased $\delta^{13}C$ values of bulk diet of Dongying humans given the high $\delta^{15}N$ over animals as referred in the previous text, whereas direct consumption of millets might offer an alternative explanation although to what degree plant food contributed to the $\delta^{13}C$ values of proteinaceous tissue in a mixed diet is unknown (Fernandes *et al.*, 2012).

Pig and dog raising practices

A majority of the pigs and dogs from both sites relied heavily on C_4 foodstuff, which were almost certainly millet-related (Pechenkina *et al.*, 2005; Barton *et al.*, 2009). This result confirms the argument that the two species commonly scavenged on human leftovers (Pechenkina *et al.*, 2005; Hu *et al.*, 2009). The mean $\delta^{13}C$ value of pigs at Dongying is about 2.8‰ higher than those from Wayaogou. This probably suggests that pigs from Dongying were fed with more millet-related feed. Hence, it is likely that agriculture surplus was more commonly used as fodders for pig at Dongying than at Wayaogou.

Pig populations at both sites were quite variable in $\delta^{13}C$ and $\delta^{15}N$ values and so were Dongying dogs. Most of them display isotope values similar to those of humans, confirming their reliance on millets (Pechenkina *et al.*, 2005; Guan *et al.*, 2008; Barton *et al.*, 2009). However, several outliers produce quite negative $\delta^{13}C$ values and fairly low $\delta^{15}N$ values, which are consistent with herbivores feeding on a mixed C_3/C_4 diet. This suggests that there could have been two distinct ways of keeping the animals. While majority were kept with an intensive foddering strategy, a smaller amount were kept with an extensive herded raising strategy (receiving less millet fodder). Consistent with our results, stable isotope analysis of domestic pigs and dogs also display the same patterns at Dadiwan (Barton *et al.*, 2009), and Kangjia (Pechenkina *et al.*, 2005) in the Wei River valley as well as Taosi (Chen *et al.*, 2012), Wadian (Zhang *et al.*, 2010b), Xinzhai (Wu *et al.*, 2007) and Xinglongwa in North China (Liu *et al.*, 2012). Therefore, we propose that intensive foddering was the major pig raising strategy in Neolithic millet farming communities in North China. In fact, this hypothesis is also supported by archaeological evidence, such as pig confinements unearthed at Wayaogou, Xipo, Jiangzhai and other Neolithic sites (Pechenkina *et al.*, 2005; Luo, 2009; Wang, 2011). In the case of extensive herded raising strategy, although it is difficult to be tested, parallel examples did exist in the Han Dynasty and even today in the more remote areas of China, where pigs are herded outdoors frequently (Liu & Zhang, 1981).

Sheep and cattle husbandry

Archaeological evidence indicates that sheep (*Ovis aries*) and taurine cattle (*Bos taurus*) were initially domesticated somewhere in West Asia during the 11–12th millennia BP and then spread across the Eurasia (Bar-Yosef & Meadow, 1995; Zeder, 2008). Though when and how they came to China are still open to debate, as *Bovidae* remains belonging to the Yangshao period or earlier have been sporadically discovered (Lü, 2010). Longshan period is generally considered to be the earliest phase of sheep and cattle domestication in the Yellow River region on the basis of zooarchaeological investigations (Flad *et al.*, 2007; Yuan *et al.*, 2007; Luo, 2009; Lü, 2010). Therefore, stable isotope analysis of *Bovidae* remains at Wayaogou and Dongying can provide insight into the early feeding practices of these two exotic domesticates. Our study will also allow archaeologists to investigate on when these animals were first introduced to the Wei River valley.

Isotopically, Dongying domestic sheep show a mixed diet similar to Wayaogou wild ovicaprids; however, the components of C_4 plants in their diets might be different. As domestic sheep could be differentiated in foraging experience from wild ovicaprids because of herding maintenance, that is, provisioning and supplementation, millet byproducts might have been included to feed them, especially during lean winter and wet days (Balasse *et al.*, 2006; Makarewicz & Tuross, 2006). In contrast, the elevated $\delta^{13}C$ values of Wayaogou ovicaprids were likely related to the presence of C_4 grasses in grasslands where these animals grazed.

For a better understating of how the early domestic cattle were raised, $\delta^{13}C$ values of Neolithic cattle and cervids in and around the Wei River valley are plotted in Figure 4. Cervids display similar $\delta^{13}C$ value patterns through time, whereas cattle's $\delta^{13}C$ values increased from pre-Yangshao to Longshan periods, indicating increasing reliance of C_4 plants in their diet. Take DDW-1 *Bos* and Wayaogou ovicaprids as the baseline of wild grazer and browser, wild *Bos* should present similar isotope ratio pattern in the region, which appears to be demonstrated in the Wayaogou *Bos*. However, a Kolmogorov–Smirnov nonparametric independent sample test ($p = 0.03$, <0.05) claims that

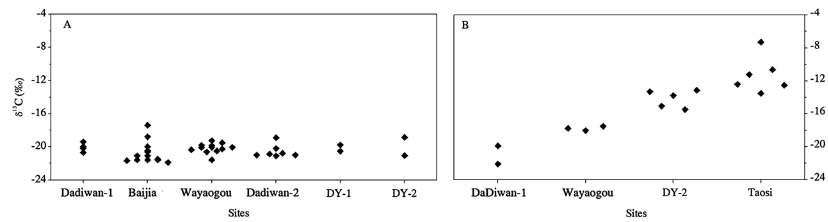

Figure 4. Stable carbon isotope compositions of cervids (A) and cattle (B) in Neolithic sites [Data of Dadiwan (ca 7.9–7.2 kyrs BP, 6.5–4.9 kyrs BP), Baijia (ca 7.7–7.4 kyrs BP) and Taosi (ca 4.4–3.9 kyrs BP) are available in Barton et al., 2009; Atahan et al., 2011; Chen et al., 2012].

there was a significant difference in $\delta^{13}C$ values between Wayaogou and Dongying *Bos* populations, suggesting that Dongying cattle's foraging experience were distinctive from wild ruminants. Considering the invisible differences between cervid $\delta^{13}C$ values statistically (Kolmogorov–Smirnov nonparametric independent sample test, $p = 0.80$, >0.05), climate fluctuation could not be the only reason behind the alteration of $\delta^{13}C$ values in plants. Accordingly, we speculate that the elevated $\delta^{13}C$ values were presumably resulted from the consumption of substantial amount of millets, probably in the form of millet foddering. In fact, the cases at Taosi and Zhangdeng have provided parallels that millet had long been used for cattle husbandry since the Longshan period (Chen *et al.*, 2012; Hou *et al.*, 2013).

Conclusion

Our project here reports $\delta^{13}C$ and $\delta^{15}N$ data to trace the shift of livestock raising practice and its relationship with millet farming in the Wei River valley. As expected, Dongying humans mainly subsisted on millets and millet-fed domesticates, whereas rice consumption was relatively rare if any according to their high bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. Both pigs and dogs at Dongying had elevated $\delta^{13}C$ values relative to those at Wayaogou, indicating the increasing importance of millet farming in animal husbandry over time. Interestingly, different feeding practices are revealed by the intraspecies disparity in $\delta^{13}C$ values of both pig populations: whereas most domesticates display heavy reliance on millet feeds, others with lower $\delta^{13}C$ values likely consumed less millets. These differences were probably due to different animal husbandry practices adopted by each group, namely intensive and extensive-herded managements, respectively. As new numbers in Longshan herds of the region, diets of sheep and cattle were different from those of pigs and dogs to some extent according to their isotopic signals. Because Dongying sheep present similar isotope patterns to Wayaogou wild ovicaprids, it appeared that the farmers at Dongying might have allowed their herds to graze on nearby grassland in most cases. The relatively elevated $\delta^{13}C$ values of Dongying cattle indicate that they probably had incorporated more millets in their diet than the sheep. It is also worth to note that the elevated $\delta^{13}C$ patterns in domestic cattle in comparison with that of the wild ruminants in the study region suggested that isotope study can be used as a useful indicator for tracing the origin of cattle husbandry in North China.

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